FORMABILITY & WORKABILITY OF METALS

PLASTIC INSTABILITY & FLOW LOCALIZATION

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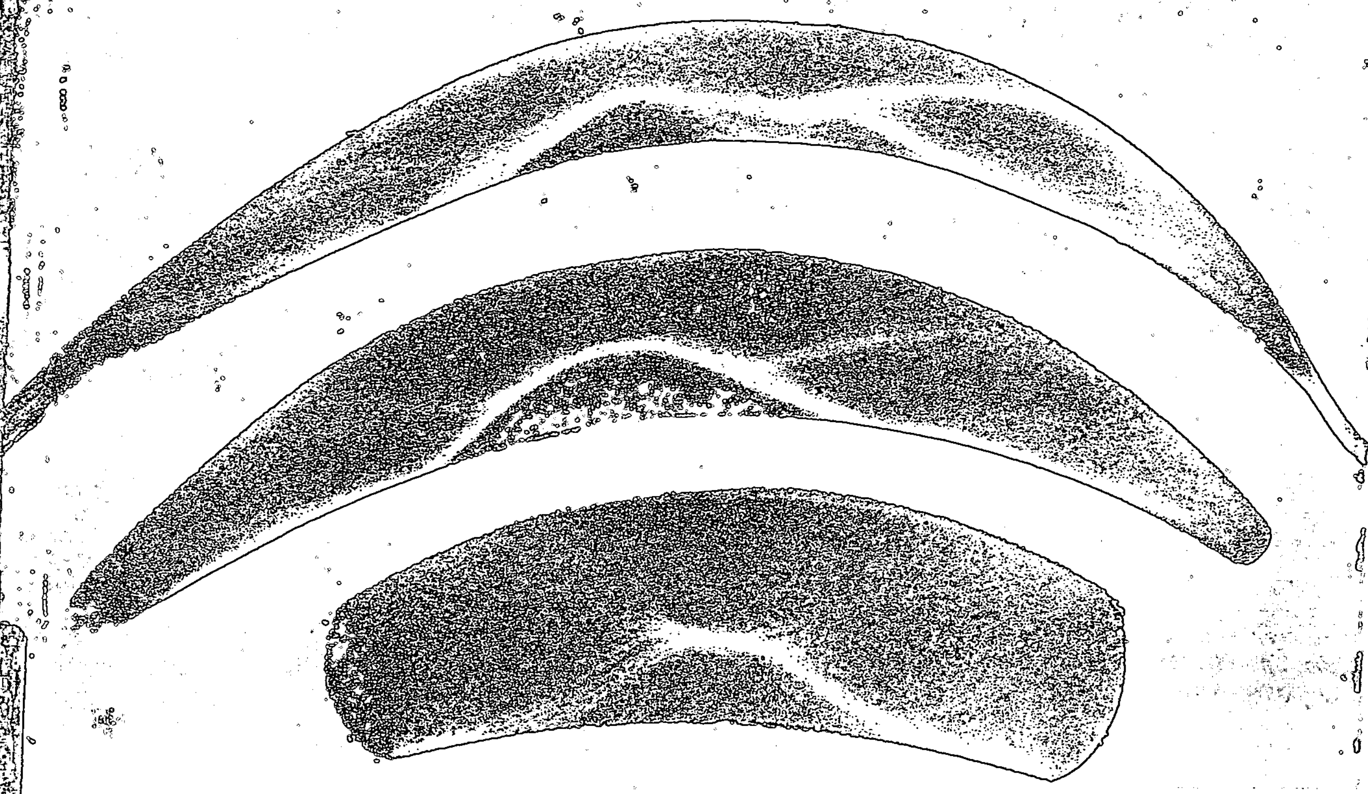

American Society for Metals

ditions of proportional straining, in which the ratio of the strain (and strain-rate) increments remains fixed. For this type of deformation, the differential signs may be eliminated from Equations (2.16) and (2.17). These equations and Equation (2.14), or similar equations for anisotropic metals, may then be inserted into equations such as (2.6), (2.7), (2.8), and (2.9) by replacing σ_1 with $\bar{\sigma}$, ε_1 with $\bar{\varepsilon}$, and $\dot{\varepsilon}$ with $\dot{\bar{\varepsilon}}$. For nonproportional straining, the stress, strain, strain-rate relationships can be obtained only by using the differential forms of Equations (2.6), (2.7), (2.8), and (2.9) in conjunction with Equations (2.14), (2.16), and (2.17) and integrating over the strain path employed.

Workability Tests

UNIAXIAL COMPRESSION TEST

One of the most common and the simplest of all workability tests is the uniaxial compression or upset test. It is used to obtain flow stress data and workability estimates for a number of bulk forming processes. In the test, a right cylindrical specimen is compressed between flat, parallel dies. When the test is used to determine the

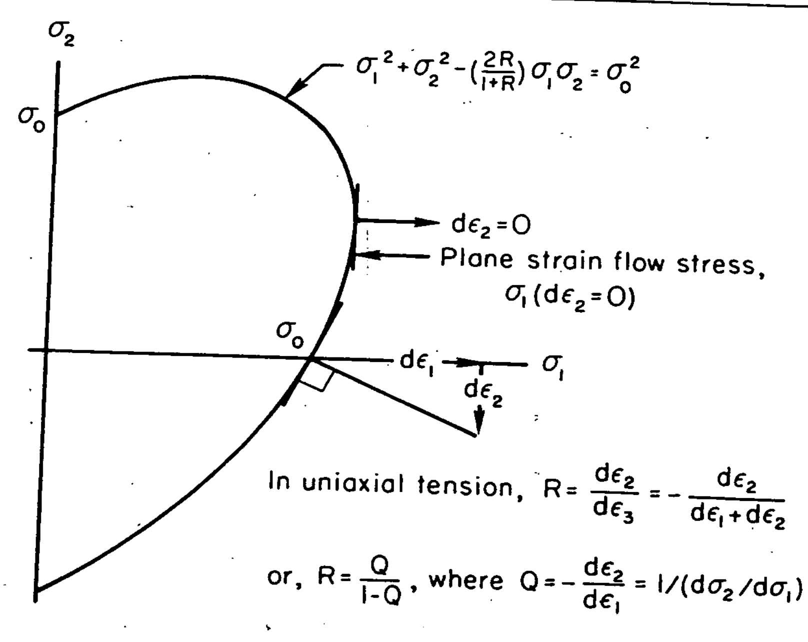

Figure 2.3. Relationship between R value and yield locus shape under conditions of uniaxial tension.

Chilling

deformation resistance, or flow stress, as a function of strain, strain rate, and temperature, dies heated to the same temperature as the specimen and appropriate lubricants are used to ensure that the deformed shape of the specimen remains as close to cylindrical as possible, i.e., without chilling or appreciable bulging. Die materials include hot work die steels and tungsten carbide (for T ≤ 500 °C, or 932 °F) and nickel-base superalloys, TZM molybdenum, and silicon nitride (for T > 500 °C, or 932 °F). A variety of die heating methods are available, including furnace heating and induction heating. Furthermore, a variety of lubricants may be employed. At ambient and slightly higher temperatures, common lubricants include PTFE (Teflon®) film, graphite, and molybdenum disulfide. At temperatures between 100 °C (212 °F) and 550 °C (1022 °F), graphite, applied by spraying a water-based solution, is the lubricant most frequently used. A variety of glasses that melt and retain a certain degree of viscosity at high temperatures are the usual lubricant choices above 550 °C (1022 °F).

Details regarding test procedures and data analysis of the compression test, when used for flow stress determination, are contained in another volume of the monograph series. Briefly, however, the important relationships used to reduce measured load-stroke data, if the deformation is uniform, are the following:*

$$\text{Axial true strain, } \varepsilon_1\text{: } \bar{\varepsilon} = -\varepsilon_1 = -\ln(h/h_o) \tag{2.18}$$

$h \equiv$ instantaneous height of the specimen

$h_o \equiv$ original height of the specimen

$$\text{Axial true strain rate, } \dot{\varepsilon}_1\text{: } \dot{\bar{\varepsilon}} = -\dot{\varepsilon}_1 = -(v/h) \tag{2.19}$$

$v \equiv$ crosshead speed

$$\text{Axial true stress, } \sigma_1\text{: } \bar{\sigma} = -\sigma_1 = -(P/A) = -(Ph/A_oh_o) \tag{2.20}$$

$P \equiv$ instantaneous load

$A \equiv$ instantaneous cross-sectional area

$A_o \equiv$ original cross-sectional area

Often the compression test is used to obtain workability data for use in bulk forming process design. For example, insight into the

*Note that compressive strains, strain rates, and stresses are negative. Similarly, the crosshead speed (v) and compressive load (P) associated with the test are also negative.

modes of flow localization and free-surface-fracture is often obtained by running compression tests on specimens of various h_o/d_o ratios (d_o = original specimen diameter) under different conditions of lubrication. The free surfaces of the specimens are gridded by photographic or electrochemical means, and grid measurements following deformation are used to obtain failure loci (Figure 2.4).[11]

The upset test is also commonly used to establish the modes of strain localization during nonisothermal metalworking operations (tooling and workpiece at different initial temperatures). In these cases, specimens heated to a particular temperature are compressed various amounts between flat dies that are heated to somewhat lower temperatures. The localization phenomena produced in this way are studied through a variety of means. These include (1) metallographic techniques in which chill zones and free-surface bulging can be measured directly and (2) analysis of the load-stroke curves through comparison with load-stroke curves from isothermal compression tests. The application of powerful finite-element techniques, which use material property data and processing conditions as inputs, is also proving useful in establishing the sequence of localization events during nonisothermal compression and other nonisothermal metalworking operations.

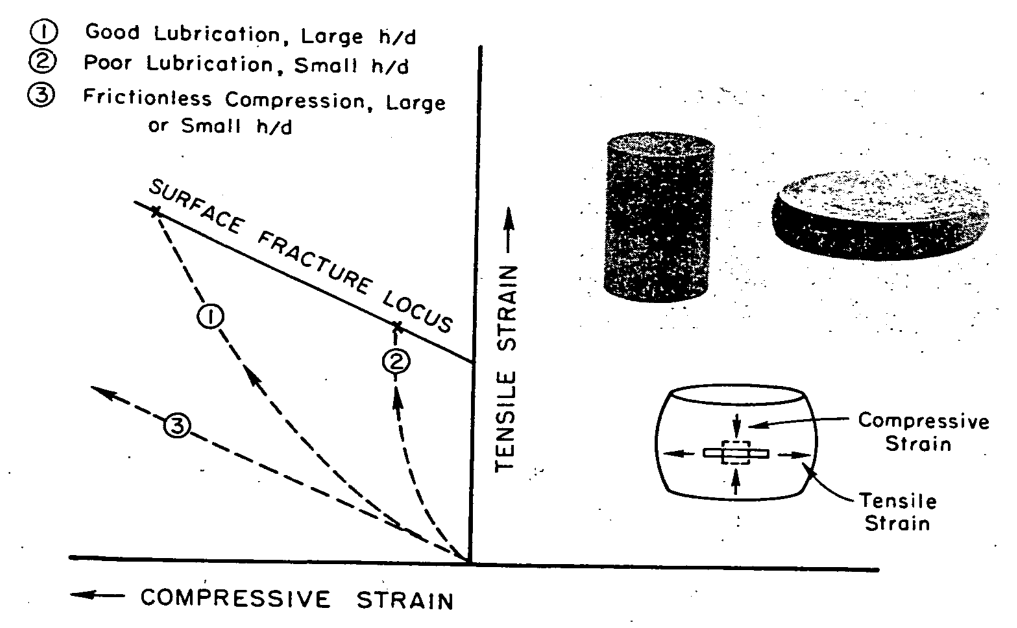

Figure 2.4. Typical failure locus of metals that develop surface cracks during bulk forming, an example of which is shown in the photograph. Locus is in terms of the free-surface compressive and tensile principal strains at failure.[11]

Titanium

A Technical Guide

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TRADITIONAL MACHINING OF TITANIUM

General

The term "machining" has broad application and refers to all types of metal removal and cutting processes. These include turning, boring, milling, drilling, reaming, tapping, both sawing and gas cutting, broaching, planing, gear hobbing, shaping, shaving, and grinding.

The technology supporting the machining of titanium alloys basically is very similar to that for other alloy systems. Efficient metal machining requires access to data relating the machining parameters of a cutting tool to the work material for the given operation. The important parameters include:

- Tool life
- Forces
- Power requirements
- Cutting tools and fluids

Subsequent paragraphs discuss these parameters in general terms.

Tool Life

Tool-life data have been developed experimentally for a wide variety of titanium alloys. A common way of representing such data is shown in Figure 6.1 where tool life (as time) is plotted against cutting speed (fpm) for a given cutting tool material at a constant feed and depth in relation to Ti-6Al-4V. It can be seen that at a high cutting speed, tool life is extremely short. As the cutting speed decreases, tool life dramatically increases.

Titanium alloys are very sensitive to changes in feed, as in Figure 6.1. Industry generally operates at cutting speeds providing long tool life. Curve fitting of tool life to feed, speed, and other machining parameters is commonly being done by means of computer techniques. However, in cases where no data base exists, certain rules of thumb should be recognized. For example, when cutting titanium, a high shear angle is produced between the workpiece and chip, resulting in a thin chip flowing at high velocity over the tool face. High temperatures develop, and, since titanium has low thermal conductivity, the chips have a tendency to gall and weld themselves to the tool cutting edges. This speeds up tool wear and failure. When dealing with high-fixed-cost machine tools, production output may be much more important than a cutting tool's life! It thus may be wise to work a tool at its maximum capacity, and then to replace it as soon as its cutting efficiency starts to drop off noticeably, thereby maintaining uptime as much as possible.

When machining titanium in circumstances in which production costs are not of paramount concern, it is still unsound practice to allow tools to run to destruction. The other extreme, premature tool changing, may result in a low number of pieces per tool grind, but the lower the tool wear, the less expensive the regrinding.

Ideally, a tool should be permitted to continue cutting as long as possible without risking damage to the tool or the work but with the retention of surface integrity. The only way

MACHINABILITY

AND

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CHAPTER 1

PRINCIPLES OF MACHINING

Introduction. In the processing of engineering and commercial parts in a manufacturing plant, such as gears, axles, drive shafts, valves, housing, screws, and bolts, the cost of machining is frequently the largest single item of expense. The necessity of keeping such costs to a mimimum justifies a thorough study of the machining processes in each plant, especially as regards the relative ease of machining of the various metals and alloys, and also of the ways in which the machinability can be improved when cutting a certain material. The machining of metals is a matter of substantial interest to engineers and manufacturers. Metals are machined to achieve shapes, smoothness of finish, and accuracy of dimensions which are not provided by casting, forging, or rolling processes.

"Metal cutting," or "machinability," is a broad term covering the relative ease of machining or the satisfaction with which a material is cut by sharp tools in various operations. In general, this implies the speed with which metal can be cut, but it also includes such factors as good finish and long tool life. Perhaps the best definition of machinability is:

Definition

The most machinable metal is the one which will permit the fastest removal of the greatest amount of material per grind (without resharpening the tool) with a satisfactory finish.

Ernst[3] defines machinability as a complex physical property of a metal having three distinct divisions which he terms (1) *true machinability*, suggested as a direct function of tensile strength; (2) *finishability*, or the ease with which a good finish may be obtained (probably an inverse function of ductility); and (3) *abrasiveness*, or the tendency of the material to abrade the tool—a negative property.

test. Method

The most common method of measuring and reporting machinability is the Taylor speed, which refers to the surface speed with which the metal can be cut, permitting a definite tool life. Other methods of rating or measuring machinability include:

1. Measurement of power consumed.
2. Rate of penetration of a standard drill under a steady pressure.
3. Determination of temperature generated.

While these methods of measuring machinability determine the ease of cutting the metal, the subject of quality of surface finish is not included.

NOTE: Superior numbers refer to listings under References at the end of this chapter.

In general, machinability, or metal cutting, includes the concept of tool life surface finish, and speed of cutting. Most jobs demand long tool life and high-speed cutting for economy, but at the same time, many operations require smooth surface finish. Accurate manufacture, the processing of closely fitted mating parts or the production of duplicate parts to small dimensional limits, is inseparably bound with surface quality.

The full understanding of the definition of "machinability," is still lacking. Arguments have been advanced for the idea that machinability should apply to the material being cut and exclude factors having to do with the tool, lubricant, and nature of the cutting operation. This would require a standardized tool and one of diamond or carbide practically impervious to wear, at least resistant enough that its shape and sharpness of cutting edge would not change during the test.

Such a course would render obsolete the often used test for machinability which refers to the life of the tool to breakdown or to the criterion that attempts to relate machinability to the power consumption of the machine tool.

Many references to the friction between chip and tool (rather than to the temperature reached at the tool tip) indicated that this criterion was thought to be a valid measure of the machinability of metal. But it must be remembered that on the one hand uniform supply of cutting fluid to the working point of the tool would be hard to ensure because it is doubtful that a gap always exists there, while on the other hand dry cutting would be so different in nature from most machine-shop operations that dry tests had doubtful value.

Actually, a single index of machinability related to the material is elusive, because of variability in the reaction of a single metal in different machining operations. For example, a completely spheroidized steel was best for machining and finishing bearing balls, but this same steel sawed and drilled better if the microstructure retained a little pearlite. Likewise, a tough continuous ferrite which was desirable for turning operations would tend to fill and seize the flute of a drill or lodge between saw teeth. Again, two different types of steel heat-treated to very similar physical properties and microstructure could produce about the same tool wear when cut under identical conditions but have a very different quality of surface finish.

The limiting condition of machining is, generally, tool failure; hence the question of the machinability of metals is unavoidably tied up with questions of tool design, form, material, cooling, and so on. Also the relative efficiency of different types of cutting tools and tool steels varies with the character of material being cut and the cutting conditions, so that generalizations as to machinability are difficult perhaps to the point of impracticability.

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